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navigational aids will be upgraded and standardized at more airports.

HUMAN FACTORS IN GENERAL AVIATION

Introduction

For tens of thousands of years man was a pedestrian on earth, slowly moving and slowly developing his skills and abilities. Yet within the short span of one lifetime he has taken to flying, left his feet and developed the ability to fly. In the history of aviation, there have been two major challenges:

(1) the design and construction of aircraft, and

(2) the training of men to operate them safely.

The response to the first challenge was and is one of mankind's great accomplishments: aeronautical engineering was born and prospered and technological breakthroughs were achieved as airplanes became bigger and flew faster, higher, and longer.

In response to the second challenge, the relatively few men sufficiently skilled and qualified to become operators were selected. During World War II, as airplanes became more complex, there was increasing emphasis on training and training processes. By the end of the war, the capacity to build complex weapons systems and vehicles, particularly aircraft, had considerably exceeded the ability of the average man to operate them. A movement to "humanize" these systems developed. Instead of searching for the "right man for the right job," the job was built around the man. An interdisciplinary area emerged, variously called human factors, engineering psychology, or human engineering; its goal to examine man's uniquely human skills and limitations, his sensory, cognitive, and perceptual-motor capacities, and to apply this information to the design of equipment, vehicles and artificial environments.[34]

VanCott and Altman viewed the emergence and development of human factors as a process occurring in three historical stages:

(1) Primary emphasis on the machine with the human "adapted" to it by means of selection and training;

(2) Primary emphasis on man where the machine is adapted or designed for the man; and,

(3) The newly emerging emphasis on the overall system design in which man and machine components are optimally integrated to achieve system objectives.[35]

A complex man-machine system in general aviation has been brought forth involving man as operator with aircraft, navigation, communications, and air traffic control systems. A concept of growing prominence is that man-machine systems (including men and machines) should be designed to capitalize on those human talents and characteristics that are of optimal use in the system as a whole, i.e., to design the environment and the man-machine interface so as to make optimal human performance not only possible but predictable.[36]

As general aviation operations have expanded, human variables have become increasingly more important. Technological advances have been achieved but flight places demands on man which would have been unthinkable a life-time ago; behaviors such as paying no attention to his senses, moving in three-dimensional space without a visual horizon for reference, and monitoring dozens of instruments simultaneously.

The Human Component: The Individual

Flying holds a unique place in the lives of most pilots. Often a pilot during flight sees the aircraft as an extension of himself. Yet according to Yanowitch, et al. if a pilot accumulates stress in his life with which he can no longer cope, that aircraft may become an instrument of self-destruction. In the context of flying the pilot may engage in subintentional self-destructive acts. These include such behaviors as neglecting important items on the pre-flight check, taking-off with barely enough fuel, or flying an aircraft which has been poorly maintained.[37]

Based on information presented in *NBAA Business Flying* (1974), a typical pilot profile shows that he is most often male, well-edu-

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[34] McCormick, E. J., *Human Factors Engineering*, 2nd Ed. (New York: McGraw-Hill Book Co.), 1964.

[35] VanCott, H. P. and Altman, J. W., "Procedures for Including Human Engineering Factors in the Development of a Weapons System," WADC Tech. Rep. No. 56-488, Wright Air Development Command, WPAFB, Ohio, October, 1956.

[36] Kidd, J. and Van Cott, H., "System and Human Engineering Analysis," Chapter 1 in Van Cott and Kinkade (eds.) *Human Engineering Guide to Equipment Design*, Rev. Ed. (Washington, D.C.: American Institute for Research) 1972.

[37] Yanowitch, R., Bergin, J. and Yanowitch, E., "The Aircraft as an Instrument of Self Destruction," FAA AM 73-50 Federal Aviation Administration, Department of Transportation, Washington, D.C., March 1973.

cated, earns a good income, has probably seen active duty with the military (but not necessarily as a pilot), is most frequently married and has never been divorced, and is, on the average, 36 years old.[38] General aviation pilots appear to be exemplary American citizens.

While fewer than five percent of all pilots are women (36,000 out of a total of 758,000), the average female pilot is slightly younger than her male counterpart. As a group, general aviation pilots appear to better educated than the average American citizen with about 80 percent having had at least some college education. More than 60 percent of general aviation pilots earned income in excess of $15,000 in 1973. Their marital status appears similar to that of the general population.

While there has been an increase of about 250 percent in the number of certified airmen over the past 23 years, the average general aviation pilot is getting older. For example, in 19[illegible] about 70 percent of the pilots were under 3[illegible] years of age while less than 50 percent are today. Fortunately, many of the complex psychological functions required of pilots depend upon judgment, reasoning, and experience and these have been found to be very resistant to deterioration with age. MacFarland pointed out that i[illegible] native mental ability, motivation, and interest remain high, no significant adverse trends in mental performance by pilots need to be expected up to the age of 55 or 60.[39]

There are some human abilities, however, that have been found to deteriorate substantially with age in the general population. These include vision, hearing, memory for recent events, and reaction time. Unless the design of general aviation aircraft accommodates this age trend, many pilots will have to conclude as did Ralph DeBruler in an article entitled "Age 60 On Final?":

> So my time of reckoning is at hand. I will take another check ride. This time I will do it on an airport where I am a stranger, where I do not know the instructor, and where I am not familiar with the airplane. . . . If I do well in the checkride, I will fly a while longer. In any case, there is a decision point some time in the future. I hope I can recognize it when it comes and accept it with grace.[40]

Pilots sometimes see themselves as a breed apart and tend to think of themselves as somewhat different fom other men in their approach to life. In an attempt to determine how the personalities of general aviation pilots compared with average adult males, Novello and Youseff administered a battery of psychological tests, including the Edwards Personal Preference Scale, to 170 male general aviation pilots.[41]

In comparing the average general aviation pilot with the mean of males in the general United States population, the pilots were found to score significantly higher on five factors: (1) **achievement** (to accomplish tasks), (2) **exhibition** (to talk about personal adventures), (3) **dominance** (to argue for one's point of view), (4) **change** (to do new things), and (5) **heterosexuality** (to be interested in members of the opposite sex).

General aviation pilots were found to score significantly lower than the average United States male on seven factors: (1) **deference** (to do what is expected), (2) **order** (to have things organized), (3) **affiliation** (to participate in groups), (4) **succorance** (to have others provide help), (5) **abasement** (to accept blame), (6) **nurturance** (to assist others), and (7) **endurance** (to work hard at a task).

Novello and Youseff concluded that there is, indeed, a core of personality traits common to pilots. They termed this core an "aviation profile" because it was also manifested by Navy pilots. The authors went on to describe the personality of general aviation pilots.

> This aviation profile fits well with the popular description of pilots in song, movie and verse as courageous, romantic "he-men". From a psycho-analytical point of view, this profile appears to describe an active-masculine or "phallic" male, that is, a man who is oriented toward demonstrating his strength and competency, who thrives on adventure, who finds pleasure in mastering complex tasks, and whose manifest sexual orientation is decidely heterosexual.[42]

Training

In addition to the airplanes themselves, equipment used in general aviation training ranges from relatively simple procedureal trainers to full-scale simulation systems. Pro-

[38] *NBAA Business Flying*, Section III, 1974, Table II

[39] McFarland, R. A., *Human Factors in Air Transportation* (New York: McGraw Hill Book Company, 1953.)

[40] DeBruler, R. M. "Age 60 On Final?" *The AOPA Pilot*, July 1975

[41] Novello, J. and Youseff, Z. "Psycho-social Studies in General Aviation, Part I, Personality Profiles of Male Pilots." *Aerospace Medicine*, February 1974 pp. 185-188

[42] *Ibid*

cedure and familiarization trainers are used to teach nomenclature and procedures, to provide the student pilot with an opportunity to practice techniques, and to develop concepts during exposure to different situations. Skill trainers and simulators are used to allow the pilot to practice responses to a wide variety of situations. [43, 44]

Fidelity of simulation refers to how realistically the flight situation is represented in the trainer or simulator. A rule of thumb has been that as fidelity increases, so do the costs of construction and maintenance of a simulator. Although high fidelity in simulation has been thought essential to good practice situations and to gain acceptance and motivation on the part of the student, recent research reveals that practice on inexpensive, low fidelity flight trainers can produce savings in terms of flight hours up to 50 percent. [45]

According to Bryan [46] and Bowen, **et al.**, [47] some tasks which can be simulated in a flight trainer and for which the student pilot is scored in terms of his performance are: checklists (ground and airborne), communications (ground and airborne), flight maneuvers, instrument navigation, and malfunctions.

In addition to providing individualized flight training, task trainers have been developed to provide simultaneous experience to a group of student pilots, each of whom is seated at an individual station while the instructor operates the training system from a console. Radio voice procedure represents an example of an appropriate task for such a training setup.[48]

[43] Miller, R., "Psychological Considerations in the Design of Training Equipment," WADC Tech. Rep. No. 54-563, Wright Air Development Command, WPAFB, Ohio 1954

[44] Kinkade, R. and Wheaton, G., "Training Device Design," Chapter 14 in Van Cott and Kinkade (eds.), *Human Engineering Guide to Equipment Design*, Rev. Ed., Washington, D.C.: American Institute for Research, 1972

[45] Cox, J., Wood, R., Borem, L., and Thorne, H., "Appearance Fidelity of Training Devices for Fixed Procedure Tasks." Tech. Rep. 65-4, Alexandria, Va.: Human Resources Research Office, 1965

[46] Bryan, G. L. and Regan, J., "Training System Design," Chapter 13 in Van Cott and Kinkade (eds.), *Human Engineering Guide to Equipment Design*, Washington, D.C.: American Institute for Research, 1972

[47] Bowen, H., Bishop, E., Promisel, D., and Robins, J., "Assessment of Pilot Proficiency," NATRADEVCEN Tech. Rep. No. 1614-1, Naval Training Devices Center, August, 1966

[48] Kinkade and Weston, *op. cit.*

[49] Hellister, W., LaPointe, A., Oman, M. and Tole, J., "Identifying and determining skill degradation of private and commercial pilots." Rep. No. FAA RD 73-91 Federal Aviation Administration, Washington, D.C.: Department of Transportation, 1973

[50] *NBAA Business Flying, op. cit.*

Until check rides were recently required, active pilots by definition were those who held current medical certificates. Maintenance of active status, however, did not imply that the pilot actually flew since they updated their certificates merely by undergoing periodic physical examinations.

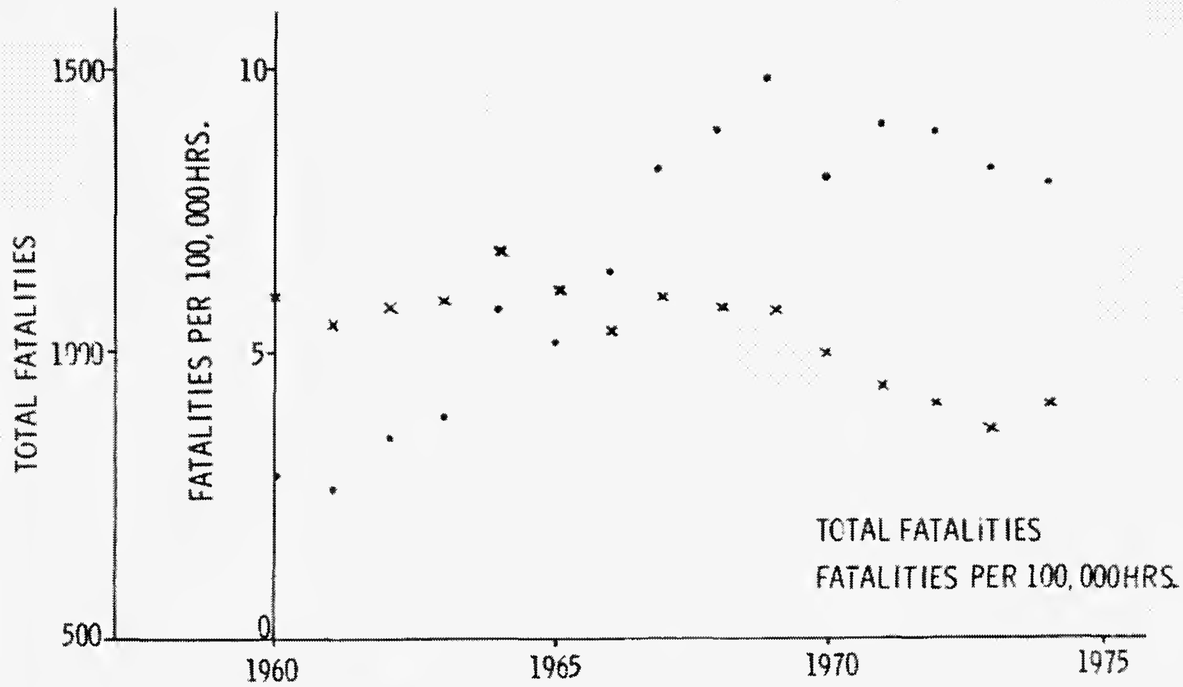
Following the old rubric of "use it or lose it," flying skills degrade rapidly when they are not used, but return rapidly with practice. Thus, simulators can be beneficial in maintaining and in upgrading flight skills. Hellister found that a group of experiential flight factors accounted for 25 percent of the variance between individual general aviation pilots (30 percent of the variance was due to individual differences and 45 percent was due to random variation, interaction effects, and noise in the measurement process). The importance of the variance attributed to experiential factors is that it can be reduced by practice. To bring a pilot with degraded skill back up to standard in one learning session, 0.6 hours of flight for each year spent with no flying was required. [49]

Employment

Predictions have been made that the employment level of active airmen will be driven up steadily over the next decade. In 1974, *NBAA Business Flying* reported that there were approximately 53,500 pilots employed in civil aviation in 1972 of whom roughly 22,000 flew general aviation aircraft. Considering the total number of certified airmen in the United States, a relatively small proportion earn their livelihoods by flying. Tentative Bureau of Labor Statistics figures reported in the same issue of *NBAA Business Flying* estimated that approximately 68,000 pilots were employed in civil aviation in 1973. [50]

Accidents and Safety

The final analysis and identification of the causes of all accidents, whether in air transportation or in general aviation, are the legal responsibility of the National Transportation Safety Board (NTSB). Generally, airline crashes and fatal general aviation accidents are investigated completely by the Board itself. Some accident fact-finding jobs, however, are assigned to the Federal Aviation Administration. Among these are the preliminary investigation of non-fatal general aviation accidents. Though thorough and painstaking, most general aviation accident inquiries give the impression that a unique occurrence has been investigated, one that has not happened in the past and which could not happen again. No lore of general aviation aircraft accidents has been



Source: National Transportation Safety Board, 1974 Data

GENERAL AVIATION FATALITIES 1960-1973
FIGURE 1-10

built up for there is little transfer of design implications from one accident to another.[51]

Introducing a discussion of accidents, Hoekstra and Huang stated unequivocably that "the safety record of general aviation in the United States over the period 1959 - 1969 reveals that flying was much safer at the end of the period than at the beginning." [52] Figure 1-10 reveals that the record is not quite as good as those brave words imply. The number of total fatalities has increased markedly over the period 1960 - 1973, but then, so have general aviation activities. The rate of fatalities per 100,000 hours flown, a more comparative index because it is free of activity level, is indeed lower in 1973 than it was at the beginning of the period, and considerably better than the worst year, 1964. To conclude that there has been any marked gain in safety over this particular period would be imprecise because of the up and down fluctuation of the curve. By regarding a much longer period of time, such as a span of 50 years, one can truly say that flying has become much safer since today's aircraft are much more reliable than they were in the days of World War I when two-thirds of all air casualties were caused by accidents, not enemy action. [53]

Since general aviation encompasses many types of flying activities, one can determine which activities have better or worse safety records. In 1968, in terms of the rate of accidents per 100,000 flying hours, business, transport, commercial flying, and air taxis had the best records while experimental flying, personal flying and other non-commercial flying had the worst as shown in Table I-VIII. From these data one can make the observation, for example, that Instructional Flying, while contributing a high number of total accidents (Rank =2) was, nonetheless, safer than several other forms of general aviation flying.

The phases of operation of an aircraft at the time an accident occurs are presented in Table I-IX with the percent of total accidents which occurred in each phase averaged for the years 1968 and 1969. Approach and landing operations, accounting for about 50 percent of the total accidents, appear to be the most dangerous phases of flying. In-flight accidents

[51] Beaty, D., *The Human Factors in Aircraft Accidents*, (New York: Stein and Day), 1969

[52] Hoekstra, H. and Huang, S., *Safety in General Aviation*, (New York: Carmen Printing Associates, Inc.), 1971

[53] Beaty, *op. cit.*

TABLE I-VIII

RATE AND RANK OF TOTAL ACCIDENTS PER GENERAL AVIATION ACTIVITY, 1968

Type of Flying	Rate per 100,000 flying hours	Rank by Number of accidents
Experimental, Test, Demonstration, Air Shows, Etc.	100.00	5
Other Non-Commercial Flying	32.88	7
Personal Flying	30.93	1
Aerial Application	28.63	4
Instructional Flying	15.16	2
Business Transport	13.18	3
Other Commercial Flying	11.05	8
Air Taxi	8.80	6

Source: Derived from Hockstra and Huang, *Safety in General Aviation*. Carmen Printing, New York, 1971.

TABLE I-IX

GENERAL AVIATION PERCENT OF ACCIDENTS WHICH OCCUR DURING DIFFERENT OPERATIONS

Flight Operation	Percent Occurrence
Static	0.6
Taxi	4.0
Take-off/Initial Climb	18.2
In-Flight	26.3
Approach/Landing	49.7
Undetermined	1.3

Source: Derived from data reported by Hockstra and Huang. *Safety in General Aviation*. New York: Carmen Printing, 1971.

account for slightly more than 25 percent while takeoff and initial climb is the third most dangerous maneuver with slightly less than 20 percent of the accidents occurring during this phase. Because pilot error causes the preponderance of accidents on approach and landing, a concentrated effort to improve safety performance in this particular area would yield the greatest payoff.

Accidents often involve a series of events, the occurrence of each being crucial for the accident to happen; however, statisicians treating NTSB investigative data establish single causes whenever possible. In 1968-1969 two causes were established in more than half of the cases (yielding a combined total in excess of 100 percent). The pilot was cited overwhelmingly, in 83 percent of the cases, as the cause of most general aviation accidents. Weather (21 percent) ran a poor second to pilot error, followed closely by mechanical failure (17 percent). Terrain, personnel, airport/airway facilities, and miscellaneous causes followed in that order.[54]

In recent decades human error consistently has been the highest causal category for accidents in both general aviation and in air transportation. The NTSB assigned pilot factors as causal in 58 percent of the fatal air carrier accidents for the years 1964-1969. Though better than pilots in general aviation, the figure is still too high for acceptance.

Throughout the world the idea is supported th[illegible] human factors on the part of the pilot are responsible f[illegible] of the fatal accidents; yet,

[54] Hoekstra and Huang, *op cit*

[55] Beaty, *op cit*

the general opinion seems to be that the problem is so complex that little or nothing can be done about it.[55], [56] "Pilot error" is a "basket" expression covering a number of different sorts of errors. It is easy to say that a pilot failed to use proper judgment, but hard to show how the relationship of major stiuational constraints, design, equipment or system influences contributed to a given failure in judgment. Knowing that a pilot committed an error is of little preventative value without knowing the cause, and only recently has there been increased discussion about pilot errors which are "design induced."[57]

Beaty noted that the term "pilot error" does not even begin to separate professional skill errors from more typical human errors. To him, professional skill errors occur when the pilot lacks the experience or skill to do any better. He defined human errors as those connected specifically with the fact that the person involved is a fallible human being.[58]

In March, 1971, the Secretary of Transportation ordered a study to analyze the factors contributing to general aviation safety in order to reduce the accident rate.[59] The resulting recommendations included biennial flight reviews of pilot competency, a general aviation accident prevention program, increasing the requirements for flight instructors, and establishing a standard traffic pattern rule at uncontrolled airports, among others. The recommendations appear to be a step in the right direction.

From a human factors perspective, an accident represents a total failure of the man-machine system in aviation. If pilot error is truly the major cause of aviation accidents, one can reach either of two conclusions: (1) remove this low reliability component (i.e., the pilot) from the system, or (2) redesign the system so pilot performance is optimized

Man-Machine Dynamics

The discipline of human factors has focused especially upon man-machine relationships. Some deal with the psychomotor responses of the human controlling the device or vehicle he uses; others with perceptual and cognitive human functions such as information-seeking and decision-making based on instrument displays.[60] There have been literally thousands of pilot-airplane research studies sponsored primarily by defense agencies over the past 25 years. Many of these studies have been relevant to general aviation but, unfortunately, there has not been a compilation to date. The present discussion will be limited to a brief examination of the field with a few studies cited for illustrative purposes.

In a theoretical sense, human performance must be considered in terms of various sensory, mental, and motor activities; but, in a specific task situation, human performance is inextricably intertwined with the performance characteristics of the physical equipment. In the 1940's, for example, to measure the impact of airframe dynamics on a pilot, aeronautical design engineers at the Cornell Aeronautical Laboratory built the first airplane whose stability could be varied systematically. The airplane was "black-boxed" in such a way that by impressing control surface motions on those made by the pilot, the pitch, roll, and yaw responses of the airplane could reflect those of a variety of conventional aircraft. Pilot performance, opinion, and acceptance of various frequency and damping modes were thus tested and empirical research directed toward improvement in airplane control design was initiated

Most everyone is aware the vehicular control systems having widely different dynamics may feel "good" or "bad" to the operator. Studies such as the one by von Doenhoff and Jones have led to the use of experimental pilots as "vocal adaptive controllers." General aviation aircraft designers have made extensive use of opinion ratings by test pilots in the construction of aircraft for good handling characteristics.[61], [62]

Over the years general aviation aircraft have become progressively more reliable and stable. This has not been accidental, but has grown out of continuing research and extensive trial and error. Basically, a pilot's control activity in flying an airplane can be broken into

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[56] Miller, C.O., Alexander, P., Starke, T., "The U.S. General Aviation Safety Record." Paper presented at the SAE National Business Aircraft Meeting, Wichita, Kansas, March 24-26, 1971.

[57] Kowalsky, N., *et al.*, "An Analysis of Pilot Error-Related Aircraft Accidents." Rep. No. N 74-26434, NASA CR 2444, Washington, D.C.: National Aeronautics and Space Administration, June, 1974.

[58] Beaty, *op. cit.*

[59] Assistant Secretary for Safety and Consumer Affairs, *General Aviation Safety*, *Department of Transportation Report to the Secretary*, N72-17015, Springfield, Va.: National Technical Information Service, Sept. 15, 1971.

[60] Parsons, H., *Man-Machine System Experiments* (Baltimore, Md.: The Johns Hopkins Press), 1972.

[61] von Doenhoff, A. and Jones, G., "An Analysis of the Power Off Landing Maneuver in Terms of the Capabilities of the Pilot and Aerodynamic Characteristics of the Airplane." National Advisory Committee for Aeronautics, Langley Field, Va., August, 1953.

[62] Frost, G., "Man-Machine Dynamics," Chapter 6 in Van Cott and Kinkade (eds.), *Human Engineering Guide to Equipment Design*, Rev. Ed., Washington, D.C.: American Institutes for Research, 1972.

three general categories: (1) stabilization, (2) command maneuver, and (3) event responses.

Stabilization is essentially a task of error reduction. Studies based on servo-mechanism theory, such as Westbrook's in 1959, have analyzed both the controlled element (some aspect of an airplane's control system) and the pilot's workload.[63] The performance of command maneuvers utilizes the same airplane control system as stabilization, but here the error component is neither directly displayed nor easily detected. Some command maneuvers, such as takeoff rotation in a helicopter, may even use non-visual signals; others such as airplane roll have no detectable error signal at all. Because all tracking maneuvers are a mix of command maneuvers and stabilization tasks, human factors was ultimately involved in tracking studies for many years. The studies of Levine[64] and Rockway and Franks[65] reflect this concentration. Event responses include single, discrete actions such as turning a dial or throwing a switch. A study such as Hunt's (in 1957) which recommended 15 shape-coded knobs to be used in aircraft controls is an example of research related to event responses.[66] The goal of all such research has been the improvement of pilot performance through simulator training or the improvement of system performance through airplane control systems and cockpit displays designed more optimally.

A display is considered to be any method of presenting information indirectly in some coded form. Elements of cockpits, such as some instruments and controls, have been improved in design. Nevertheless, the whole operating environment in most civil aircraft leaves much to be desired. The pilot has to fit himself in among a myriad of switches, controls, levers and dials, and adjust himself the best way he can, instead of the other way around.[67]

Not all displayed information is visual; the sense of hearing also has been utilized in the cockpit, particularly for emergency situations. Audio warning systems—such as the stall warning horn, the gear-up horn, and the radio bleeper system on ILS approach have been derived.[68]

A now classic Air Force study by Jones, Milton, and Fitts in 1949 led to recommendations for display panel layouts based on pilots' eye-movements during a climbing maneuver.[69] The applicability to general aviation of this and other layout studies became apparent in the late 1950's when the FAA modified Part 23 of the Federal Aviation Regulations (Airworthiness Standards of General Aviation Planes) to specify a "T" arrangement directly in front of the pilot of airspeed, attitude, altitude, and direction indicators. To date, however, the location of only these four instruments has been standardized. A confusing clutter is reported by many general aviation pilots who switch from one airplane to another. Other airplane displays and controls, not to mention optional navigation and communications equipment, often appear to be placed according to the manufacturer's or the first owner's whim rather than by their frequency of use or importance. Further, Beaty reported that in analyzing reactions to their own instruments, many pilots thought a number of them were confusing, particularly the airspeed indicator, altimeter, visual failure warnings on let-down, altitude instruments, and radios. There was also criticism of the general layout and design of instruments and switches.[70]

In a plane traveling at both a constant speed and altitude, orientation is no problem. But in various aircraft maneuvers—including changes in speed (acceleration), banking, and pushovers—the sensory cues received by a pilot are misleading and can give rise to disorientation. Judgments of the amount of bank have been found to be grossly underestimated while a tendency to perceive acceleration as a slight climb and deceleration as a slight dive has also been reported.[71,72] Pilots when decelerating for a landing under conditions of poor visibility may overshoot the runway by correcting for an illusion of descending too

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[63] *Ibid.*

[64] Levine, M., "Tracking Performance as a Function of Exponential Delay between Control and Display," WADC Tech Rep 53-236, Wright Air Development Command, WPAFB, Ohio.

[65] Rockway, M. and Franks, P., "Effects of variations in control backlash and gain on tracking performance," WADC Tech Rep No 58-553, Wright Air Development Command, WPAFB, Ohio, January, 1959.

[66] Hunt, D., "The Coding of Aircraft Controls," WADC Tech Rep 52-106, Wright Air Development Command, WPAFB, Ohio, March, 1957.

[67] Fitts, P. M., "Engineering Psychology and Equipment Design," In S.S. Stevens (ed.) *Handbook of Experimental Psychology*, N.Y.: John Wiley and Sons, 1951.

[68] Licklider, J. C., "Audio Warning Signals for Air Force Weapons Systems," WADC Tech Rep No 60-814, Wright Air Development Command, WPAFB, Ohio, March, 1961.

[69] Jones, R., Milton, J., and Fitts, P., "Eye Fixations of Aircraft Pilots IV: Frequency, Duration, and Sequence of Fixations During Routine Instrument Flight," USAF Tech Rep No 5975, Washington, D.C.: United States Air Force, 1949.

[70] Beaty, *op. cit.*

[71] MacCorquodale, K., "Effects of Angular Acceleration and Centrifugal Force on Non-visual Space Orientation During Flight," *J. Aviation Medicine*, 1948, 19, 146-157.

[72] Clark, B. and Graybill, A., "The Break-off Phenomenon," *J. Aviation Medicine*, 1953, 24, 88-90.

rapidly. This may partly account for the fact that there are twice as many overshoot accidents as undershoots.

Disorientation, as well as visual illusions, is enhanced under conditions of fog, darkness, or clouds when the pilot has no visual frame of reference. The effect of rotary motion and angular acceleration, particularly with reference to visual illusions, is a subject of very recent investigation.[73,74,75] An explanation is being sought for a phenomenon reported by pilots in the past of attempting to join up in formation with stars, buoys, and even street lights that appear to be moving.

The Man-Environment Interface

While many instruments on a pilot's display panel relate to the state of subsystems within the airplane, often the most critical instruments are those which give the pilot information about the relation of his plane to the external environment. Because of the high incidence of accidents during the landing phase of flight operations, considerable effort has been expended to develop flight displays which provide information the pilot could acquire otherwise by direct viewing of the outside world, but with signals added to indicate the correct flight path. A display presenting a pictorial analog of the real world has been developed by Greuther.[76] A "heads-up" display which indicates the landing site for general aviation airplanes is being investigated by NASA-Langley.[77]

Instrumentation of a plane's attitude, airspeed, velocity, flight path, and relative bearing to reference points is distributed in various locations on a pilot's display panel. During critical flight maneuvers, the pilot has difficulty integrating these sources of information. A display aid which would superimpose attitude, airspeed, heading, and position information directly on the windshield, thus removing the necessity for the pilot to search among his instruments, is presently under study by NASA. Such information could be color-coded and available to the pilot on demand.[78]

The general aviation traffic environment at uncontrolled airports has also come under NASA's scrutiny. After radar tracking at three airports and a survey of pilot preferences about landing procedures, a standardized landing pattern is being recommended to yield safer approach and landing performance at airports without towers.[79]

The last several years in general aviation have seen a marked improvement in avionics equipment.[80] Pilots get lost less frequently, the national airspace is utilized more fully, the possibility of mid air collisions is reduced, and existing airports can handle increased traffic loads more safely as a result of this "avionics explosion." Despite increased safety, an unfortunate consequence is that pilots' workload has increased. The workload is so demanding that the Learjet, for instance, requires two pilots. In many situations the pilot's tasks border on overload to the point where the pilot may not be able to handle emergencies. The use of computer technology and programming to take over at least routine monitoring functions of the pilot is seen as a possible solution to the trend of increasing complexity of the pilot's task.

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[73] Stewart, J. and Clark, B. "Choice Reaction Time to Visual Motion During Prolonged Rotary Motion in Airline Pilots." *Aviation Space Environmental Medicine*, 1975, 46, 767-771.

[74] Junker, A. and Repogle, C. "Motion Effects on the Human Operator in a Roll Axis Tracking Task." *Aviation Space Environmental Medicine*, 1975, 46, 819-822.

[75] Beck, L. "The Effect of Spurious Angular Acceleration on Tracking in Dynamic Simulation." *Human Factors*, 1974, 16, 423-431.

[76] Greuther, W. and Backer, C. "Visual Presentation of Information." Chapter 3 in Van Cott and Kinkade (eds.) *Human Engineering Guide to Equipment Design*, Rev. Ed. (Washington, D.C.: American Institutes for Research), 1972.

[77] Harris, R. and Hewes, D. "An Exploratory Simulation Study of a Head-Up Display for General Aviation Light Planes." NASA Rep. No. TN-D-7456, Langley Research Center: National Aeronautics and Space Administration, 1973.

[78] Rizsy, E. "Color Specification for Additive Color Group Displays." RADC Tech. Rep. No. TR 65-278, Rome Air Development Center, 1965.

[79] Parker, L. "Pilot Preferences and Procedures at Uncontrolled Airports." NASA Tech. Rep. No. TN-D-7928. National Aeronautics and Space Administration, Washington, D.C.

[80] Potempa, K., Lintz, L., and Luckew, R. "The Impact of Avionics Design Characteristics of Technical Requirements and Job Performance." *Human Factors*, 1975, 17, 13-24.